Information technology for construction management and building performance evaluation support: - a North-American perspective -

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ABSTRACT: We provide a critical overview of the current status of computational support for construction management and building performance evaluation in North-America. This overview is based on the research conducted in relation to the design and construction of the Intelligent Workplace (IW), Carnegie Mellon University, Pittsburgh, Pennsylvania, USA [2]. We focus on the evaluations of selected commercial and research software products particularly in view of their relevance for interdisciplinary co-operation between planners and managers as well as decision support for early stages of design.

INTRODUCTION

Before we focus on our specific topic, the use of information technology for construction management and building performance evaluation, we would like to include some selected results of the latest survey focusing on the role of computing conducted by the Education Committee of the Technical Council on Computer Practices of the American Society of Civil Engineers presented and published in [1]. One of the survey's goals was to identify the status of computing skills of new hires (or new graduates). Based on this status, practitioners asked about their expectations, and recommendations regarding specific skills that need to be improved.

Besides the desire to have all graduates be skilled in the application of CAD-packages, most of the responses contained the even stronger desire to have recent graduates consider the computer and the appropriate software packages as a problem analysis tool instead of a problem solving tool. Most of the respondents felt that new graduates are literate, but several statements also indicated concerns that recent graduates are too dependent on computers and application software. A considerable number of respondents expressed that the need for new engineers to develop stronger verification skills and a better understanding of the limitations of computers and the software packages. As application software becomes more complex and sophisticated, so are the demands on the development of certain skills such as logical approach to problem solving, debugging skills, development of mathematical algorithms and a general understanding of how computers and communication infrastructure work.

We would like to use these introductory comments to state that our evaluation criteria for information technologies in building management and building performance evaluation focus on the support which architects/engineers can gain/expect from complex software tools during the analysis of products and processes.

CONSTRUCTION MANAGEMENT

The focus of the following section is directed towards research trends in the development of construction management software packages that may be regarded as representative within the United States of America and the coverage of typical construction management software products available in the U.S. market, since a complete overview is neither feasible nor meaningful within the scope of this paper.

Construction Planning, Scheduling and Resource Allocation

SOFTWARE TOOLS: The commercially available software packages are distinguished within two categories (1) high end packages and (2) mid range packages. The high-end packages are built on a standard data-base, have network capabilities and have larger capacity. During the mid-nineties some reviews and comparative evaluations were published (detailed information see [2]). Some specific characteristics of these tools are briefly discussed in more details in the following paragraphs.

The implementation of data entry and the representation are in most of the cases graphic-based. Various types of charts (Gantt charts, PERT charts) resource histograms, task lists and calendars are available. The data representation in various views enable the necessary flexibility. Data can be edited either in the graphical representations or within the tabulated forms.

Project scheduling tasks are in most packages managed by using the Critical Path Method (CPM). Most of the high-end packages will allow a version management. Some of the packages can disassemble a project into subprojects to be distributed to individual managers. Changes of the subprojects are automatically inserted into the master plan when the subprojects are reassembled.

Resource histograms are available in most of the packages as well as automatic leveling functions to reallocate resources. The user can control the percentage of completion of construction by time, cost, and work in most of the commercially available software tools. Various reports can be generated easily. A detailed cost monitoring is possible in most of the packages because features like incorporated inflation factors, overtime cost rates, and comparison of actual versus budget costs are available. The level of networking capabilities varies. Selective features such as file locking or multi-level password protection are not available in every package. File based data exchange is available within all of these packages. Some of the high-end packages offer superior integration with other software.

RESEARCH: There are two major research foci in general:

(1) Efforts to facilitate or automate specific project management tasks more efficiently, and
(2) Efforts to develop integrated computer systems that allow effective communication among the various specific planning tasks as well as the cooperation with other planning and design activities.

Researchers at the University of Michigan developed a case based planning and scheduling system. Their research activities focus on the reusability of contractors' experiences from repetitious and similar projects for the planning of new facilities. A general product model is used to model facilities and organize planning options.

Other research activities in the early nineties focused on AI-application, rule-based expert systems, and knowledge based expert systems. More detailed information is available in [2.] pp. 92 to 94.

Cost Estimating

SOFTWARE TOOLS: Many software tools can generate detailed cost estimates by using automatic quantity take-off process with CAD-systems. Material databases are available for users and can be modified by users to specify building materials associated with building elements. Some tools can act as an integrator, collecting relevant design and quantity data from various CAD-systems and integrate these data into a final cost estimate.

Few software packages have incorporated extensive decision support functionalities. The decision support is available through historical cost data based on existing buildings and the capability to extend the existing database with cost data from self designed projects.

Construction Simulation and Visualization

SOFTWARE TOOLS: The number of commercially available software packages with construction simulation and visualization capabilities are limited.

RESEARCH: Most of the methods that attempt to describe / simulate construction processes lack the capability to incorporate the geometric component of building projects. The abstract representation of complex building cycles in Gantt charts or CPM schedules represent the ability to communicate a progression of construction activities over a certain time. But there still exists a need for the development of software packages which allow architects / engineers and contractors / subcontractors to simulate and visualize construction sequences. The ongoing research effort at the Center for Integrated Facility Engineering (CIFE) at Stanford University is focusing on this problem. Researchers at CIFE develop a so called 4D-CAD system. A 4D-CAD represents time and space. It can be considered as a graphic simulation of a process. The simulation involves the combination of a 3D-graphic model and a construction schedule. The objective of the visualization part of the CIFE 4D CAD system is not to build a 4D-CAD VR tool Researchers at CIFE are focusing on the development of a tool which simulates the various stages of a construction process and to visualize these stages.

Research at the School of Civil and Environmental Engineering at the Georgia Institute of Technology (GATech), Atlanta focuses on the VR-aspect. The research approach at GATech intends to place designers, construction managers and other users into a virtual scenario. Researchers at GATech develop an object oriented virtual environment which provides the user with several choices of virtual construction equipment. The virtual construction equipment is able to receive instructions and carries out tasks needed to assemble buildings. It is controlled by reactive control algorithms and thus able to adapt changes in the environment. Instead of finding ways to model the system so the simulation runs correctly, the user can interact with the system.

The system model consists of six basic objects: camera, light, terrain, machine, building, and building object.

Building objects are the basic elements for a built object. These building objects are arranged in an hierarchical or sequential fashion. The hierarchy is determined by the relationships that exist between these objects. The sequences represent the order in which the building objects have to be assembled.

Each building describes an object that requires an assembly process. The assembly sequence is contained in the building object definition file and can be extracted by the planner. She / he is able to distribute the contained task descriptions to the appropriate machine.

Machines are composed of objects. These objects interact with each other in a hierarchical fashion. The capability of interaction is achieved by the implementation of behavior-modules. The terrain object serves as physical support for all components (building objects and machines).

Camera and light are necessary accessories for the graphical representation / visualization.

BUILDING PERFORMANCE SIMULATION AND EVALUATION

In the beginning we discuss problems of computational building performance and simulation tools. In this context building performance stands for the evaluation of the behavior of buildings and their systems regarding energy use and the thermal environment, as well as the control of natural and artificial lighting, acoustics and air quality. Issues of building performance are usually covered within the field of "Bauphysik" and "Klimatechnik" in German-speaking countries. Next, a brief review of the current research and the state-of-the art tools is given. The focus of the following section is directed towards research trends that may be regarded as representative within the United States of America and the coverage of typical products available in the U.S. market, since a complete overview is neither feasible nor meaningful within the scope of this paper.

Energy and Buildings

The topic of *energy and building design* could be discussed from several perspectives, such as HVAC-system design, impacts of enclosure and lighting systems, peak loads, and energy conservation. The focus of this part is sizing of HVAC-equipment by the HVAC-designer and the analysis of energy consumption, because the current use of the energy-related software tools is dominated by these topics.

SOFTWARE TOOLS: The numerous tools available in the U.S. market can be characterized as follows:

- The thermal process model of most of the available tools is incomplete. Although the more sophisticated tools consider transient conduction, short-wave radiation, and air-exchange they typically do not take into effect long-wave radiation, convection, air-flow, detailed thermal interaction between building and the surrounding environment.
- There are various building models, specifying various levels of resolution, implemented within these tools. The more sophisticated tools use for example a multi-layer description to model walls which allows for modeling transient conduction and thermal bridging.
- The accuracy of HVAC-system and plant modeling varies from purely empirical to very detailed models. The empirical models describe the HVAC-equipment as single units with certain operating characteristics, and typically contain no information on physical dimensions, fluid properties, flow rates, pressures, temperatures, etc. The detailed models are component based and employ more specific information.
- The external environment is modeled to various levels of detail. For example temperature effects can be characterized by the degree-day method or by the more sophisticated hourly weather data files.

RESEARCH There are two major research foci in general:

(1) Efforts to improve the accuracy and reliability of the models and algorithms used for the calculations, and
(2) Efforts to effectively integrate the use of simulation for design decision support.

Research in the first field includes:

The SPARK object oriented model-lab environment, developed at the Lawrence Berkeley Laboratory, is intended to provide the ability to build detailed simulation tools using low-level objects that encapsulate fundamental heat and mass transfer equations.

The use of neural networks to monitor and accurately predict energy consumption in existing buildings is demonstrated in the research of the University of Colorado, Boulder.

Last but not least, we would like to mention that there are also efforts to enhance existing tools. For example DOE-2 is regularly updated with more accurate ways of simulating various building and HVAC-system components.

A number of research efforts have been made to integrate the use of simulation for design and decision support. A large project, that involves Pacific Northwest Laboratory, Lawrence Berkeley Laboratory, California Polytechnic Institute, and the University of Oregon is the AEDOT-project (Advanced Energy Design and Operation Technologies). AEDOT is intended to provide design advice and guidance to support qualitative and quantitative aspects of iterative and interdisciplinary design, construction, and operation tasks of buildings.

Researchers at the Center for Building Performance and Diagnostics are developing *SEMPER*, an active multi-aspect computational tool integrating building performance simulation (energy, lighting, and acoustics) into computational design systems. Specifically *SEMPER* seeks to meet the following requirements: (1) a methodology consistent performance modeling approach through the entire building design and engineering process; (2) seamless and dynamic communication between the simulation model and the general building representation; (3) a "preference-based" performance-to-design mapping technology for active design support.

Natural and Electrical Lighting

This is in relationship to software capabilities and research efforts for analyzing daylighting, and electrical lighting. We do not consider the design of indoor electrical lighting systems in this paper.

SOFTWARE TOOLS: Few commercially available software tools provide daylighting evaluation. Most of them consider electrical lighting design and evaluation. The following evaluation of currently commercially available software is based on a survey of the Illuminating Engineering Society of North America (IESNA).

Most of the tools predict illuminance in a sufficient way; however, they are limited in that they only give an average value for the reflected component of light throughout the space. This is because of the use of the zonal cavity method.

Some programs calculate luminance but few of them resolve these luminance finely enough to produce images.

The more advanced lighting simulation programs use ray-tracing and radiosity techniques. The incorporation of daylight evaluation is rare in commercially available software products. Very few of them consider the integrated effect of daylight and electrical lighting. As mentioned earlier, only some of the software tools are able to provide plots of the illuminance of the space as output. Most of them only provide numerical output results.

Most of the tools typically cannot model internal partitions, light shelves, and complex geometries, such as curved walls and ceilings, sloped ceilings, and sloped apertures. Lighting simulation tools are less used by building designers but often used by lighting-design consultants. As a result the scope for integrated evaluation and decision making is rather limited.

RESEARCH :

The research foci in this area are comparable with the general research foci within the energy related research.

(1) Efforts to improve the accuracy and reliability of the models and algorithms used for the calculations.
(2) Efforts to effectively integrate the use of simulation for design decision support.

The research in improving accuracy and reliability includes:

The extension of the use of radiosity, which was basically developed in the area of computer graphics, for lighting evaluation. This includes the combination of radiosity and ray-tracing techniques to model both global diffuse and specular components of light, and a progressive refinement approach for fast image generation. Work on these topics was performed in the late eighties at Cornell University. During the same time researchers at Lawrence Berkeley Laboratory worked on the detailed simulation of the solar-optical properties of multi layer fenestration systems.

In the early nineties research efforts focused on the development of more accurate daylight modeling, including more realistic modeling of the sky. Research was performed at the University of Berkeley, the University of Michigan, and the State University of New York. As an alternative to the daylight factor method, the coefficient of the utilization method has been studied at the Pennsylvania State University.

Research activities to efficiently integrate the use of simulation tools for decision support includes:

The development of "GESTALT" an daylighting simulation environment that allows for the simultaneous modification and observation of changes in design and performance variables. The tool was developed at Carnegie Mellon University (CMU), Pittsburgh, PA. Currently, researchers at CMU are attempting to develop tools that support integrated design of daylighting with electrical lighting design.

Air Quality

Air quality issues have become important with the increase in Sick Building Syndrome and other building air quality problems over the last decade. However, air quality modeling and simulation has not become a part of building design practice to the extent that energy and lighting modeling have, because of its complexity and the expensive computational demands. It is mostly still in the research domain.

SOFTWARE TOOLS and RESEARCH: An international survey of 50 tools analyzing infiltration and ventilation air flow distribution was performed at the Lawrence Berkeley Laboratory by Feustel [FEU '92]. In relation to software systems integration the survey revealed that none of the examined tools have CAD input or graphical output. Few of these tools are coupled with pollution migration tools or thermal models. Feustel also notes that the development of multi-zone infiltration and ventilation models was very slow and that there is less difference between models developed in the early seventies and those developed in the late eighties. Since the early nineties computational fluid dynamics (CFD) has been applied to the study of natural ventilation, air conditioning, and smoke movement. However, until recently the success in the application of CFD models was largely dependent on the skills of the operator in dealing with the definition of the geometry, and the specification of boundary conditions. The recent increase in computational power of desk-top computing led to an increased use of CFD in commercially available software products, such as FLOVENT (U.S. distributor: Flomerics, Westborough, MA)

Summary

In the domain of ***building performance simulation and decision support*** one can notice that the development and application of computational tools is industry driven. As a result the concerns addressed by the tools are mainly issues pertaining to the selection and sizing of systems and components rather than an integrated performance evaluation. Consequently, these programs are rarely used by building designers, especially in the early design stages, where the predictive capabilities of simulation tools could be of significant value. Although many research institutions address the necessity for the integration of performance simulation within the overall design support environments, most of the available performance simulation tools still remain mono-dimensional and isolated. This fact reflects the sequential character of the building design, planning and construction process as well as the fragmented nature of the building industry. Truly integrated design and analysis software systems are still not available.

With regard to the commercial software products in the field of ***construction management*** the following limitations can be identified: although project planning, cost estimating and construction simulation are supported, tasks like bidding as well as site and material management have not received the same level of attention. Few project management software packages are integrated in a total design support software system and the data entry still remains a strenuous procedure. Most packages still represent a "static" view of data. Little analysis or evaluation options are provided to support managerial decision making. Various research groups address the construction planning and scheduling, construction contracting, site layout generation as well as the integration of these three topics. Currently problems such as efficient material management and calculation of environmental and energy responsive site management are insufficiently addressed within the ongoing research projects.

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